

FINAL REPORT YEAR-1

Adjustable Focus Optical Correction Lens (AFOCL)

Contract NAS8-00118

Submitted

July 24, 2001

Prepared by

Dr. Bruce R. Peters

Center for Applied Optics
The University of Alabama in Huntsville
Huntsville, Alabama 35899

TEL: 256-824-2526
petersb@email.uah.edu

Final Report, Year-1 for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

Prepared by Dr. Bruce R. Peters
Center for Applied Optics
The University of Alabama in Huntsville

Technical Summary:

This report describes the activities and accomplishments along with the status of the characterization of a PLZT-based Adjustable Focus Optical Correction Lens (AFOCL) test device. The activities described in this report were undertaken by members of the Center for Applied Optics (CAO) at the University of Alabama in Huntsville (UAH) under NASA Contract NAS8-00188. The effort was led by Dr. Bruce Peters as the Principal Investigator and supported by Dr. Patrick Reardon, Ms. Deborah Bailey, and graduate student Mr. Jeremy Wong. The activities outlined for the first year of the contract were to identify vendors and procure a test device along with performing the initial optical characterization of the test device. This activity has been successfully executed and test results are available and preliminary information was published at the SPIE Photonics West Conference in San Jose, January 2001. The paper, "Preliminary investigation of an active PLZT lens," was well received and generated response with several questions from the audience.

A PLZT test device has been commercially procured from an outside vendor: The University of California in San Diego (UCSD) in partnership with New Interconnect Packaging Technologies (NIPT) Inc. The device has been subjected to several tests to characterize the optical performance of the device at wavelengths of interest. The goal was to evaluate the AFOCL similar to a conventional lens and measure any optical aberrations present due to the PLZT material as a deviation in the size of the diffraction limited spot (blur), the presence of diffracted energy into higher orders surrounding the focused spot (a variation in Strehl), and/or a variation or spread in the location of the focused energy away from the optical axis (a bias towards optical wedge, spherical, comma, or other higher order aberrations). While data has been collected indicative of the imaging quality of the AFOCL test device, it was not possible to fully characterize the optical performance of the AFOCL alone because there were significant optical distortions due to fabrication related issues.

The initial device appears to have significant amounts of bias in the lens, even when no voltage is applied. This is consistent with the imaging data acquired and is likely attributable to the mounting procedure used by NIPT and UCSD. The substandard quality of the optical mounting and fabrication of the device places an overwhelming bias on the measurements making it difficult to separate true optical performance from poor manufacturing. While issues of optical bonding and attachment of electrodes are all technologies readily available from the electronics industry, NIPT has very limited access to equipment and processes to improve their fabrication quality. Given the current limited capabilities of UCSD/NIPT, it is doubtful that the quality of their production could be significantly increased without unreasonable increases in financial backing that is not evident at this time.

Alternative vendors have been identified within the United States (NZ Technologies Inc.) and several in Europe; but initial contact has not been well received. NZ has positioned itself to be a supplier of active optic components and Spatial Light Modulators for the high volume production in the communications industry and is uninterested in producing special research devices at this time. Likewise, the variety of European potential suppliers are more university based and as such, their capabilities may be equally limited as UCSD/NIPT and as such may not be capable of producing a better quality device.

It is suggested that procurement of additional devices to proceed with subsequent years of research and technology demonstration as outlined in the original proposal may be of limited if any value. The current testing could continue along with additional testing not previously proposed to better understand the performance of the AFOCL and to attempt to extract meaningful data from the aberrated test device.

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

Introduction:

The need for on-orbit adjustment of an optical system is becoming more imperative as the design and fabrication of lighter weight, higher wavefront quality, large aperture telescopes continues. The decreased weight of the next generation ultra-light very large optics has limited the inherent stiffness of the optical elements. This increases the probabilities of developing optical surface deformations and degrading optical system performance. Traditional on-orbit realignment of telescopes typically relies on refocusing and realignment of selected optical elements (physical translations and rotations). However, high-resolution space telescopes prefer to limit mechanical displacement of optical elements to minimize undesired vibrations. A great deal of development is underway to create small robust actuators suitable for telescope alignment and as actuators in active or deformable mirrors.¹ The extreme vacuum of space places demands on the long-term stability of the materials and lubricants, often requires heaters to prevent freezing of components, and is limited with regards to response time required to achieve a precise movements. Therefore, nonmechanical approaches to optical correction are being explored.

One approach has been to develop electro-optical devices that can modulate and steer an optical beam without relying on physical displacement of the optical components. Several forms of optical phased arrays have been proposed that utilize a variety of electro-optical materials to impose a modulation of the optical phase front to achieve deflection, focussing, and aberration correction.² Such devices affect the phase front of the optical beam in a way that is similar to the way diffractive optical elements, holographic optical elements, anamorphic high-order lenses, and spatial light modulators (SLM) can affect the phase front. In so doing, they are able to impose a particular desirable phase profile onto an incident beam and thereby improve optical quality of the beam. Typically, the optical system is modeled and the aberrations are calculated or measured and wavefront correcting optics are introduced into the optical path to essentially reverse or minimize the degradation in the optical quality. While the magnitude of the phase front manipulation is more limited with electro-optical devices compared with conventional transmissive optics, the versatility of the electro-optical devices permits them to perform dynamic phase manipulation within carefully defined limits. In this fashion, the electro-optical approaches can provide potentially greater flexibility to the optical designer since the devices are capable of correcting a larger range of aberrations and adapting to a larger range of wavefront errors. The adaptability of electro-optical devices is what makes them so attractive. Liquid-crystal,^{3,4} LiNbO₃ crystal,⁵ along with PLZT⁶⁻¹⁰ have all been demonstrated as candidates for application to dynamic devices. Typically, a change in voltage applied to the device or to subapertures or pixels within the device will produce an electro-optic effect that that perturbs the optical property of the material that then modifies the transmitted phase front. One material in particular, polycrystalline lead lanthanum-modified zirconate titanate (PLZT) is attractive because the material demonstrates a strong quadratic electro-optic effect at moderate voltages. The electro-optic coefficient of PLZT is typically larger than other candidate materials and the material is typically less expensive and easier to handle. When compared to liquid crystal, PLZT can have a faster response time and can more readily be integrated into the electronic circuits.

PLZT-based electro-optical devices have been demonstrated for many applications including tunable gratings, optical switches, dynamic lenses, high-speed shutters, and scanning devices. Because of the scattering properties of the material and the strength of the electrical field required to produce a substantial phase modulation, the PLZT devices are typically made very thin and use surface electrodes. However, the solid-state nature of the PLZT makes it ideal for integration with conventional electronic circuits and thereby reduce the complexity of the device with regards to the number of external connections and controls. In fact, the integration of voltage controlling resistors and support circuitry has been demonstrated for a PLZT beam-steering device with only two external electrical connections required.¹¹ This paper describes a similar application of PLZT to fabricate an adjustable focus optical correction lens (AFOCL) to perform variable focusing and integrated wavefront correction. The purpose is to create a system that achieves stable alignment under a variety of environments and over time by incorporating a dynamic realignment with phase front correction capability rather than adjusting the much more massive solid refractive lenses often used in optical imaging systems such as telescopes and other optical sensors.

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

Ferroelectric ceramic based Spatial Light Modulators (SLMs) have been investigated for such applications,¹²⁻¹⁵ but high-voltage requirement and large-field induced effects near the half-wave voltage have prohibited their utilization. Thinned ferroelectric materials can lower the voltage requirement and stacking or cascading several devices within the optical train can avoid large-field induced effects. The AFOCL works in transmission rather than reflection maintaining the compactness of the optical system. Differing from liquid crystal display (LCD) based devices that can have intrinsically large wavefront aberrations of their own due to the nature of their construction, the PLZT material is solid which permits it to be optically polished to minimize wavefront aberrations. Furthermore, the material could be polished into lens-like shapes to further broaden its potential through the creation of hybrid active and refractive optical elements. The application of the material beyond the visible region of the infrared spectrum has been limited. Therefore, the activity proposed here emphasized the extension of PLZT-based devices into the infrared.

References:

1. R.K. Tyson, *Principles of Adaptive Optics*, Academic Press, Boston, MA (1997).
2. G. Haertling, "Electro-optic ceramics and devices," *Electronic Ceramics: Properties, Devices and Applications*, Marcel Dekker, New York, NY, 371-492 (1998).
3. T.J. Chen, P.J. Bos, H. Vithana, and D. L. Johnson, "An electro-optically controlled liquid crystal diffraction grating," *Applied Physics Letters*, **67**, 2588-2590 (1995).
4. N.A. Riza and M.C. DeJule, "Three terminal adaptive nematic liquid-crystal lens device," *Optics Letters*, **19**, 1013-1015 (1994).
5. R.T. Chen, D. Robinson, H. Lu, M.R. Wang, T. Jansson, and R. Baumbick, "Reconfigurable optical interconnection network for multimode optical fiber sensor arrays," *Optical Engineering*, **31**, 1098-1106 (1992).
6. Q. Wang Song, X.M. Wang, and R. Bussjager, "PLZT ceramic wafer-based electro-optic dynamic diverging lens," *Optics Letters*, **21**, 242-244 (1996).
7. Q.W. Song, P.J. Talbot, and J.H. Maurice, "PLZT based high-efficiency electro-optic grating for optical switching," *Journal Modern Optics*, **41**, 717-727 (1994).
8. T. Tatebayashi, T. Yamamoto, and H. Sato "Electro-optic variable focal-length lens using PLZT ceramic," *Applied Optics*, **30**, 5049-5055 (1991).
9. J.A. Thomas, M. Lasher, Y. Fainman, and P. Soltan, "A PLZT-based dynamic diffractive optical element for high speed, random-access beam steering," *Proc. SPIE Vol. 3131*, 124-132 (1997).
10. K. Nagata, "PLZT optical shutter with copper electrodes by electroless plating," *Ferroelectrics*, **109**, 247-252 (1990).
11. Q. Wang Song, X.M. Wang, R. Bussjager, and J. Osman, "Electro-optic beam-steering device based on lanthanum-modified lead zirconate titanate ceramic wafer," *Applied Optics*, **35**, 3155-3162 (1996).
12. G.D. Love, J.V. Major, and A. Purvis, "Liquid-crystal prisms for tip-tilt adaptive optics," *Optics Letters*, **19**, 1170-1172 (1994).
13. V.A. Berenberg, A.A. Leshchev, M.V. Vasil'ev, V.Y. Venediktov, A.P. Onokhov, and L.A. Beresnev, "Dynamic correction for distortions in imaging optical systems using liquid crystal SLMs," *Proc. SPIE*, Vol. 3432, 110-119 (1998).
14. Raimo Silvennoinen, Kai-Erik Peiponen, Andris Krums and Jari Räsänen, Optical quality inspection of PLZT ceramics by using CGH-element, *Optical Materials*, **7**, 145-152, 1997.
15. Brykhar Z., Bykov I., Dimza V., Jastrabik L., Savinov A., Soukup L., Trepakov V.: Optical Spectra of PLZT Ceramics. In: *Electroceramics IV. Proc. of the 4th Int. Conf. on Electronic Ceramics and Applications.*, 431-434, 1994.

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

Activities:

UAH began the optical design and specification of the first Adjustable Focus Optical Correction Lens (AFOCL) during the summer of 1999 and finalized it by August. The design was strongly influenced by the capabilities of the fabricators: New Interconnect Packaging Technologies, (NIPT) and the University of California San Diego (UCSD). The eventual specifications to be given to NIPT and UCSD were discussed at a technical interchange meeting (TIM), Monday May 22, 2000 at NIPT in San Diego, California. The meeting involved Billy Lightsey from NASA-Space Optics and Manufacturing Center (SOMTC) at Marshall Space Flight Center in Huntsville, along with Dr. Bruce Peters and Dr. Patrick Reardon from the CAO. The AFOCL performance goals were outlined and technical objectives were discussed. NIPT provided their proposal for the PLZT active lens. During the subsequent discussion, UAH was able to provide clarification to NIPT regarding the performance goals that resulted in the relaxation of some fabrication specifications that will enable acceptable performance while minimizing technical risk.

The preliminary AFOCL specifications were as follows:

- 25mm diameter substrate
- approximately 4mm diameter active area for device
- operational wavelength to be 1.5 μm with additional wavelengths (including 2 μm and 632 nm) to be considered in the design of the device
- approximately 5 waves maximum of focus adjustment
- F-number of 100 with 40 μm pitch preferred
- PLZT active lens on a glass substrate operating in a longitudinal mode
- patterned Indium Tin Oxide (ITO) zones with Aluminum contacts with either SiO_2 (standard) or possibly Polyimide dielectric insulation layer

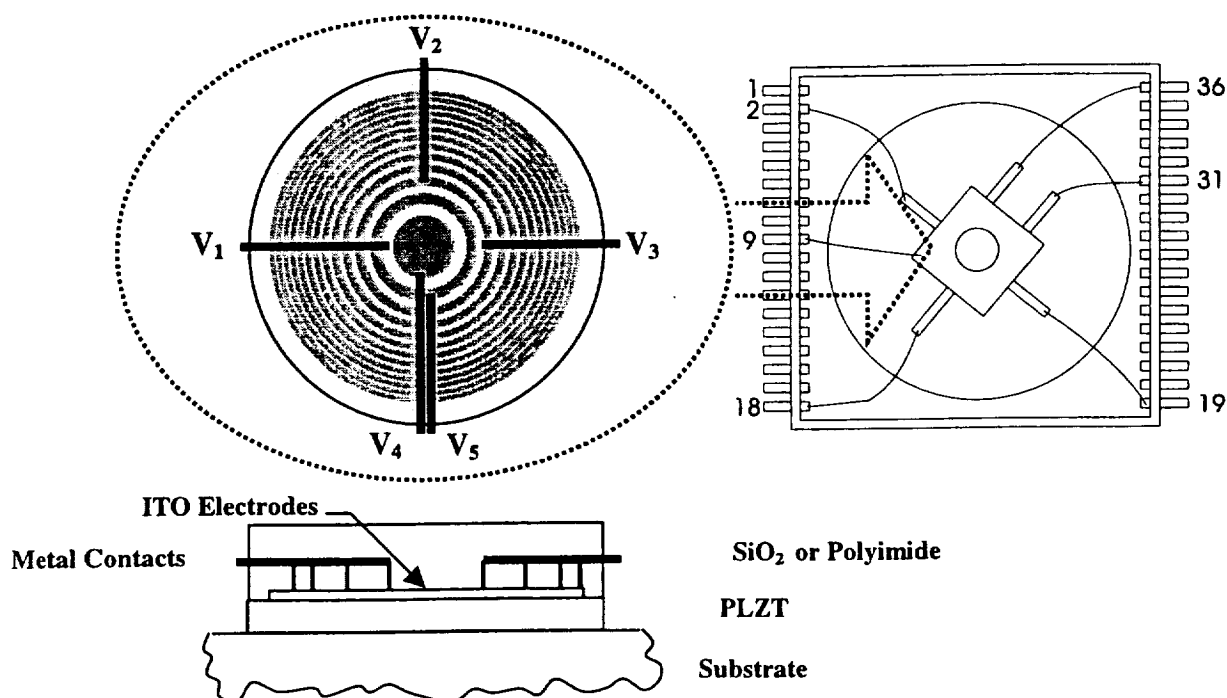


Figure 1. AFOCL Positive and Negative Lens Concept

In support of the specification of the AFOCL and to facilitate optical characterization, UAH performed optical modeling of the device. The unique nature of the AFOCL will allow it to be both a positive and negative lens by switching the order of the voltages going to the PLZT segments (Figure 1).

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

This means that the AFOCL could be tested in two different configurations and the performance characterized for both.

The AFOCL is solid state in that the refocusing and wavefront correction is accomplished through variations in the voltage applied to a thinned and stacked PLZT device instead of mechanically translating the optic. By varying the voltage to the crystal material, the optical behavior is altered. If the material is laid down into patterns or arrays, using conventional microlithographic fabrication procedures in use by the semiconductor industry, then the individual pixels can be modulated as required to create almost any arbitrary phase front desired. Concentric rings can be activated to create focussing lenses or strips can be modulated to tip and tilt the transmitted light to realign the optical path. Through a stacking or cascading of the devices, each one performing a specialized wavefront correction, virtually all optical aberrations within the system could be compensated for and eliminated from the optical train thereby leading to diffraction limited performance. In this way, larger optics could be made to less demanding wavefront qualities requirements to keep costs in check and the stacked series of AFOCL elements could be used to correct the optical alignment and improve the wavefront quality by "inverting" the aberrations to back-out errors and enhance optical performance. This is vital to having autonomously operating space-based telescopes because the sensor will need to be capable of correcting aberrations that will be changing over time (such as thermal induced defocus, mechanical stress induced aberrations on mirrors, and vibration/thermal misalignment of optical components) to maintain diffraction limited system performance.

An analysis was performed to determine the optimal design specifications for the AFOCL adaptive optic. The analysis evaluated the tradeoffs between the form of the phase function, the magnitude of the phase induced across the optic, and the structure of the annular pixels. The pixels could be of identical width, or the pixels could vary with distance from the center of the optic. These tradeoffs were measured by how they affected diffraction efficiency, manufacturability, and functionality of the device. It was determined that, for achieving the desired functionality for the device, the most appropriate pattern would be a quadratic phase function which, depending on the sign of the phase change, would yield a positive or negative lens. Since this device was to have annular "pixels," the approach to the design was analogous to a stepped-approximation to a phase grating. Thus, each ring would generate specific phase lags such that main diffracted order for the system would yield the desired lensing power. The next question to answer was how much power, and how many steps for each 2π of phase.

The efficiency of the 1st diffracted order given a stepped approximation to a properly blazed grating can be computed using the following equation:

$$E(s) = \left[\frac{\sin\left(\frac{\pi}{s}\right)}{\left(\frac{\pi}{s}\right)} \right]^2$$

where s is the number of steps. Evaluating discrete values for s yields the following results:

| Steps (s) | Diffraction Efficiency | Improvement in Efficiency |
|-----------|------------------------|---------------------------|
| 2 | 41% | |
| 3 | 68% | 41% |
| 4 | 81% | 16% |
| 5 | 88% | 7% |
| 6 | 91% | 4% |
| 7 | 93% | 2% |
| 8 | 95% | 2% |

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

By increasing the number of levels in the stepped approximation, the diffraction efficiency clearly increases, however, the percentage of improvement in the efficiency in going from N to N+1 steps is increasingly smaller as N increases. This predicted performance is analogous to the performance of any step-wise approximation to a pure phase function similar to diffractive and binary optical elements. Thus, from this analysis, we selected a 5-step approximation as it has sufficient efficiency and, as will be shown, it further simplified manufacturing.

Since the number of steps has been selected, we can now determine how much quadratic phase our device should generate. The device produces phase of the form $\Phi(r) = Ar^2$ where r is the radial distance from the center of the device. The gradient of the phase is given by $\nabla\Phi(r) = 2Ar$, and the minimum feature size can be calculated using the equation

$$\begin{aligned} MFS &= \frac{\lambda}{\nabla\Phi(r_{\max}) \cdot s} \\ &= \frac{\lambda}{2Ar_{\max} \cdot s} \\ &= \frac{\lambda}{10Ar_{\max}} \end{aligned}$$

where rmax is the semidiameter of the device and λ is the wavelength of operation, 2.0518 micrometers. Thus, the larger diameter the element and the greater the magnitude of the phase, the smaller the minimum feature size will be. Based on vendor recommendations and in order to mitigate production related risks, it was decided that a diameter of 4mm and a total phase of 5 waves, $A = 1.25\lambda/\text{mm}^2$, was appropriate. This yields a minimum feature size of approximately 40 μm that is well within the tolerances of the fabrication process and also considered to be very low risk.

The complete quadratic phase function of the device is achieved by setting every 5th ring to equal and specific voltages in such a way that the rings produce optical path delays of 0, $\lambda/5$, $2\lambda/5$, $3\lambda/5$, and $4\lambda/5$. By starting with the central disk at 0 phase, and increasing the optical phase delay on the rings as r increases, a negative lens is generated. If, however, one was to start the central disk at 1 and then decrease the optical phase delay on the subsequent rings, one would have a positive lens. Fortunately, for a diffractive lens such as this, a delay of 0 λ is identical to a delay of 1 λ , thus, the identical delays (voltages) need only be rearranged to switch between a positive and a negative lens. These results are shown graphically in Figure 2.

While the electrodes in a conventional approach are typically fabricated using optically transparent indium tin oxide (ITO), the power feeds in this device were going to be aluminum instead of ITO. Therefore, the opaque conductive lines would partially obscure and diffract some of the light. The effects of this on the throughput of the device can be readily calculated. The effects can be described in two ways. First, the lines produce a reduction in the transmitting area. Since there are 5 conductive lines, and each line is 0.040mm wide and 2mm long, they provide 0.4mm² of obscuration. Compared to the full 4mm diameter aperture, the conductive lines reduce the overall throughput of the device by 3%.

The second effect the conductive lines produce is a change in the diffraction pattern relative to an unobscured circular aperture. The pattern for the unobscured aperture is simply the Airy disk pattern (Figure 3a). The conductive lines, however, add some additional structure to the pattern. The lines consist of three parallel but displaced lines, and two parallel lines perpendicular to the other three. As can be seen in the first two plots of the point spread function, the diffraction from the conductive lines is, on a linear scale, imperceptible. Even when plotted on a log scale, the effects are negligible, though noticeable (Figure 3b).

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

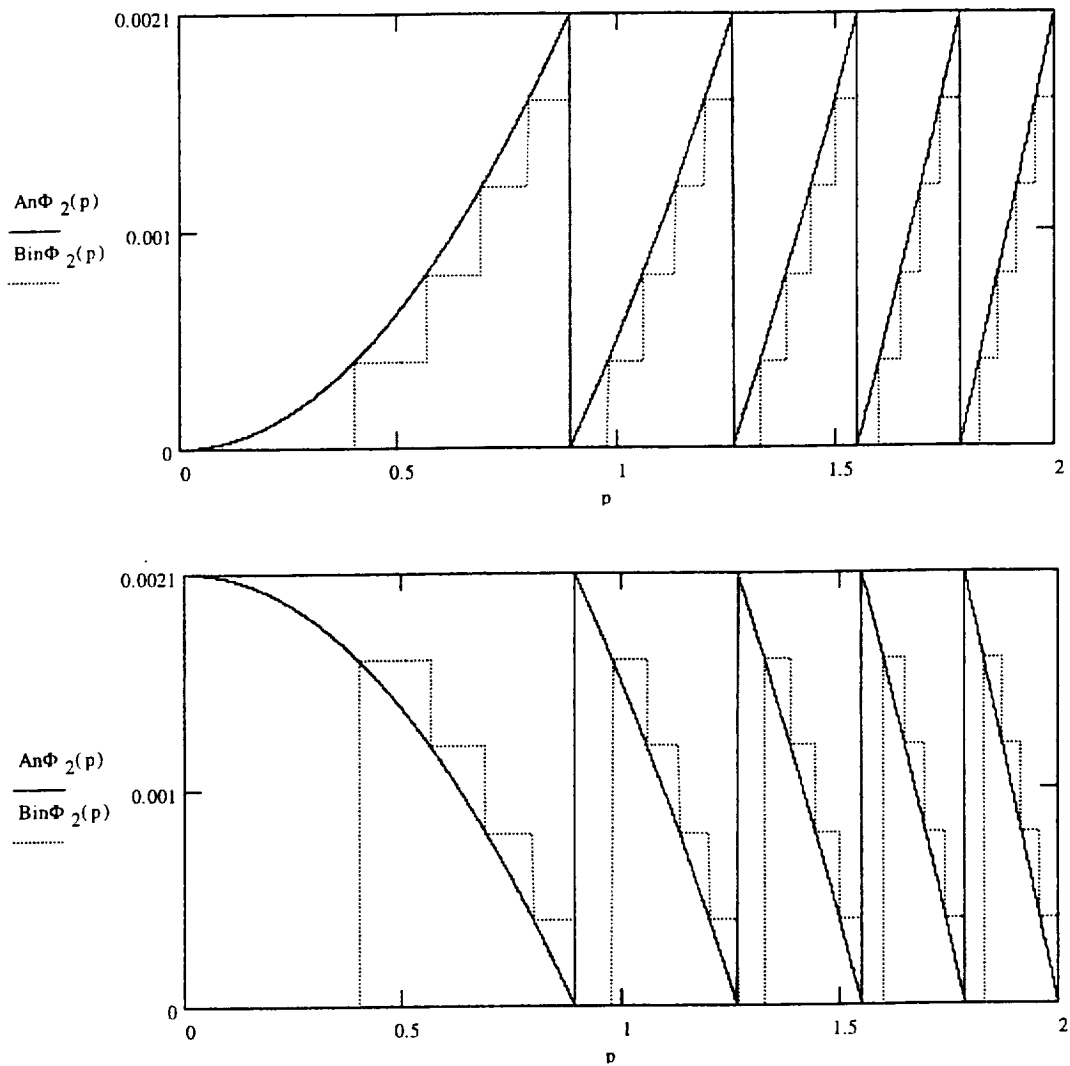


Figure 2. AFOCL Positive and Negative Lens Test Configurations



Figure 3. Modeled AFOCL Transmission

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

In preparation for delivery and testing of the AFOCL device, UAH has designed the optical system (Figure 4). The lenses, optical mounts, and other fixtures were identified and orders were placed to procure the necessary testing hardware. A commercially available positive lens and negative lens were identified to serve as an AFOCL emulator to facilitate alignment prior to the delivery of the actual AFOCL from NIPT. The emulator will permit development and characterization of the optical test set-up, serve as a known reference source for calibration of the test data, and provide a comparison to the actual AFOCL performance.

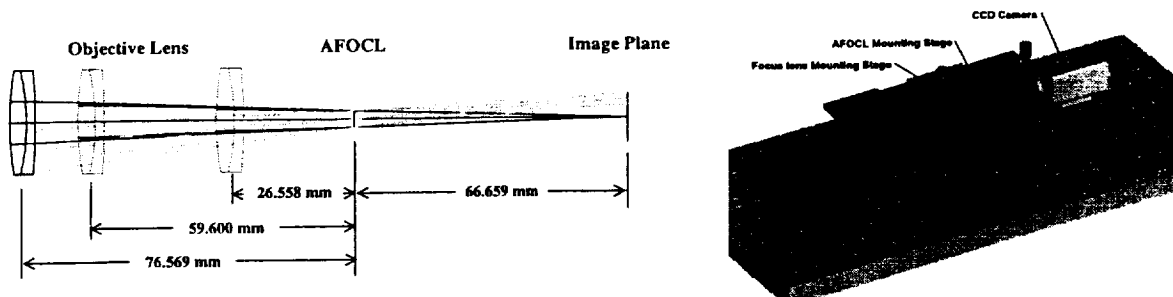


Figure 4. AFOCL Positive and Negative Lens Test Configurations

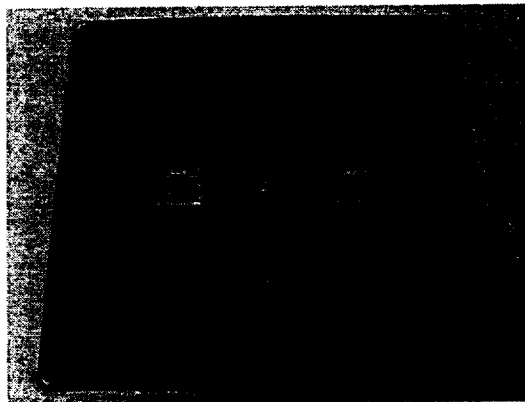


Figure 5. AFOCL Photolithographic Mask

Dr. Peters visited NIPT on Tuesday, August 1, 2000 to discuss the mask generation process and to review the proposed design. Following the successful review, the design was translated into e-beam data files to write the mask pattern. Figure 5 shows the completed masks. The fabrication specifications were finalized by August and the photolithographic masks were designed and procured. NIPT completed generating e-beam data for the photolithographic masks. UAH reviewed the design and in collaboration with NIPT, the electrode pattern design was revised from the first iteration radial pattern to one that consists of only horizontal or vertical lines to reduce the cost of the design and e-beam writing.

The test device was delivered in October with the initial checkout of the device in November to verify connectivity and continuity of the AFOCL wire bonds. The initial performance is shown optically in Figure 6. The images are taken using a CCD camera. There is no voltage to the device in Figure 6 (a) with all of the electrodes effectively connected to ground. The expanded speckled HeNe laser is passed through the 4 mm diameter aperture of the device and the resulting intensity pattern is shown (within

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

larger circle). Then, three of the ring electrodes or zones are connected to the ground and the remaining two rings to 280V, and illuminated by the laser. The device is operating as a very poor diffractive optic collecting lens (smaller circle) because the voltage is way off of the designed voltage; yet, the device does focus some of the light. Testing then began in earnest in November using the UAH designed voltage supply circuit (Figure 7).

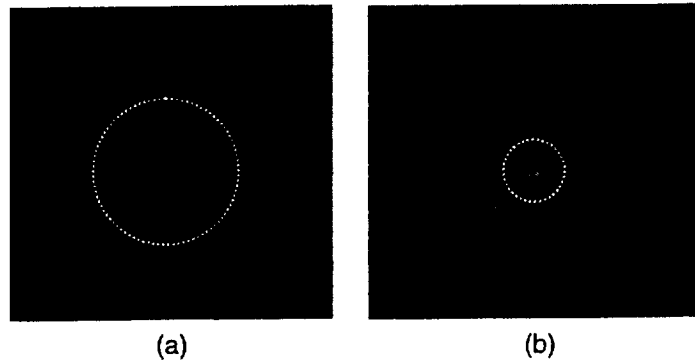


Figure 6. AFOCL Transmission Demonstration

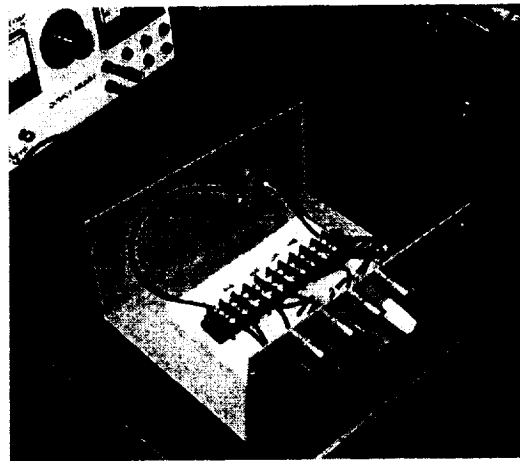


Figure 7. High Voltage Power Supply and Regulation Circuit

Testing and Characterization:

The areas to be investigated include intensimetric effects (those that limit or alter the intensity of the light transmitted through the optic); interferometric effects (the phase change induced through the optic); and polarimetric effects (evaluating the differential lag between two polarization states propagating through the optic). These distinct phenomena are often coupled together in real applications consequently, there is a need to develop different standardized testing apparatus to: (1) isolate one effect from another; (2) gather information for understanding the physical effects; (3) anchor wavefront corrector modeling efforts; (4) develop the ability to decouple different effects; (5) demonstrate the suitability of PLZT technology to perform wavefront correction.

The CAO had at its disposal, traditional interferometers available within the CAO Optical Metrology Laboratory and the Advanced Polarization Test Facility. Besides the imaging and interferometers available, the polarimetry facility has at its disposal, a Mueller Matrix Imaging Polarimeter (MMIP) which is well suited to the characterization of SLMs, polarizers, and thin film coatings within the visible and near-IR spectrums. In addition, the phase-shifting interferometry facilities at NASA-MSFC and

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

the unique interferometers they processes are some of the most advanced available and may be of value especially for performing real-time optical performance evaluation of AFOCL test components.

The testing of the initial test device supplied by UCSD/NIPT was conducted at HeHe wavelengths ($\lambda=632\text{ nm}$) for ease in setup and data acquisition. The ability of the AFOCL to focus the incident energy of a HeNe laser is shown in Figure 9. The images were taken using a CCD camera and the test setup shown schematically in Figure 8. Two different locations for the CCD camera were selected to attempt to better define the true focal length of the device.

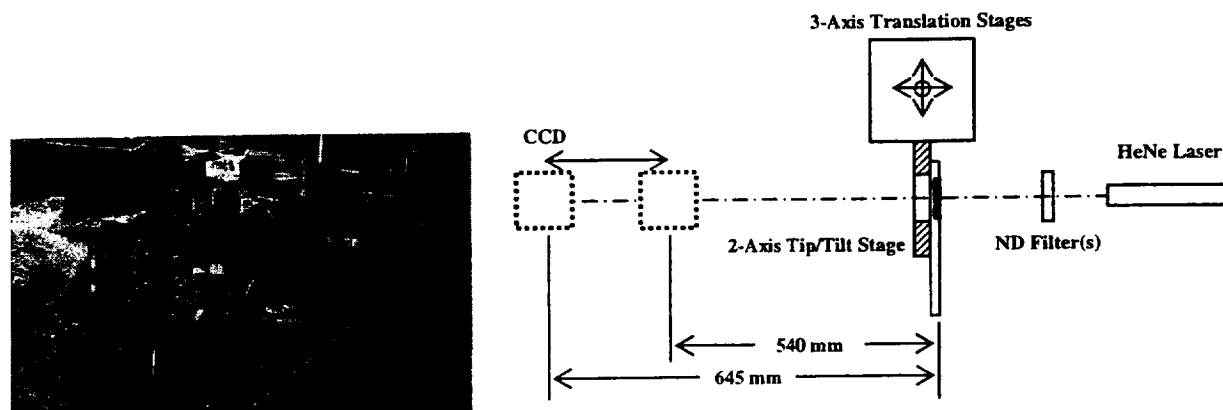


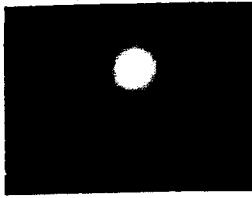
Figure 8. Focusing Test Setup.

There is no voltage to the AFOCL device in Figure 9 with the unexpanded HeNe laser transmitted through the 4 mm diameter aperture of the device and the resulting intensity pattern is shown. Then, the ring electrodes are provided current through the connections and the device voltage is increased towards an optimal calculated voltage. The underpowered device is operating as a very poor diffractive optic collecting lens at lower voltages because the efficiency of the diffractive structure is rather low. As the voltage increases, the efficiency of the diffractive increases and the focusing of the light become more pronounced as shown in smaller and more circular central focused spot. The tabulated data on the focusing of the spot as evident in the decrease in the spot diameter is shown in Figure 10.

The scattering of light around the AFOCL device is attributed to two things. The optical quality of the mounting of the AFOCL is less than desired with adhesive optical cement clearly visible at the periphery of the AFOCL active area. This cement will affect the transmitted wavefront quality and can likely be minimized or eliminated with more careful attention to the mounting procedures. Similar and better mounting procedures are readily available through commercial vendors and companies such as CCD camera manufactures who mount cover plates over CCD arrays and would not be difficult to implement. An alternative would be to place a nonelectrically conducting index matching fluid over the surface of the AFOCL that contains the excessive optical cement. This should minimize the aberrations and give a truer picture of the operation of the device. The second effect contributing to the scattering of the light is believed to be the optical effects of the electrodes within the field of view; but, this effect is small and may not be observable given the gross aberrations from the bonding.

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

Unexpanded HeNe Beam



540 mm distance from AFOCL



0 Volts



100 V



200 V



280 V

645 mm distance from AFOCL



0 Volts



100 V



200 V



250 V

Figure 9. Focusing Images.

| Measured 540 mm from AFOCL | | | |
|----------------------------|---------|-----------|-----------|
| | 0 Volts | 280 Volts | Reduction |
| Diameter | 6.10 | 3.81 | 37.50 % |
| Area | 29.22 | 11.40 | 60.99 % |

| Measured 645 mm from AFOCL | | | |
|----------------------------|---------|-----------|-----------|
| | 0 Volts | 250 Volts | Reduction |
| Diameter | 7.37 | 42.66 | 37.07% |
| Area | 5.08 | 20.27 | 52.49% |

Figure 10. Tabulated Data from Initial Checkout Test.

Interferometric Testing:

The testing of the AFOCL is emphasizing the interferometric measurements of the AFOCL device. The device was placed in the test setup as shown in Figure 11 and 12. The test is a double pass interferogram of the AFOCL with three different operational states: positive lens, voltage off, and negative lens. The maximum voltage for both the positive and negative lens configurations was 250 Volts.

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

The Wyko Tychmann-Green Interferometer uses a HeNe laser transmitted through the device. No physical aperture was used in these tests to mark the 4 mm diameter active area of the device. Instead, software in the computer integrated into the interferometer was used to select a digital aperture for data processing. The digital aperture size and location was based on the AFOCL device. The metal voltage supplying leads were used to center the digital aperture on the interferogram and the diameter was selected based on the approximate 4 mm active area. While the aperture is not exactly 4 mm diameter, the same aperture was used for all data sets so the interferograms would be consistent.

Typical interferograms are shown in Figure 13. Several interferograms were collected and stored at each of the configurations (positive lens, no voltage, and negative lens). The raw data was then transferred into the Quick Fringe software for reduction. In Quick Fringe, the locations of the fringe centers on the raw interferograms are determined and the fringes are digitized. In this fashion, contour plots of the transmitted wavefront are generated (Figure 14) for every one of the raw interferograms. All of the interferograms within one configuration are then averaged together to create the synthetic fringe plots shown in Figure 15.

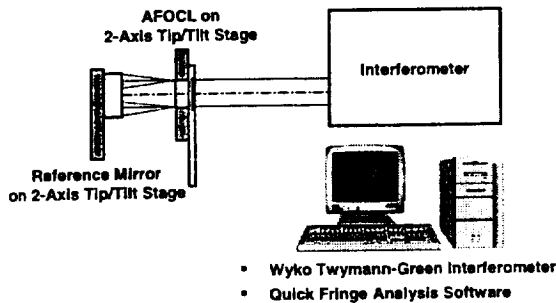


Figure 11. Interferometric Test Setup.

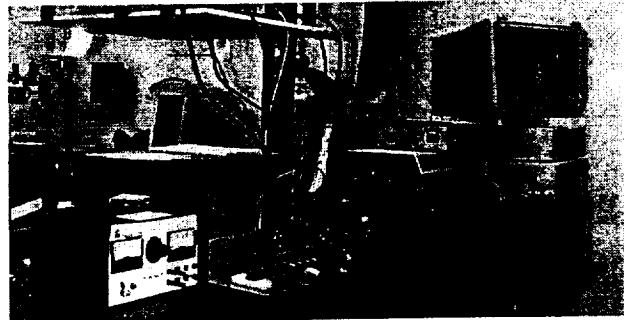


Figure 12. Interferometric Test Setup.

The data reduction of the interferograms has followed conventional software-based interferometry data reduction approaches and has produced numbers that appear to be inconsistent with hand calculations. This is attributed to the fact that the large wavefront errors produced near the edges of the AFOCL device cause such severe phase front changes that the fringe following algorithms begin to malfunction. The high phase slope is once again a result of the bad bonding at the edges of the AFOCL and as a result appear in the field of view of the interferometer. Aperture of the data will permit the algorithms to better function but the results are no longer valid since the area is so greatly reduced.

More attention is needed to address these problems and to investigate alternative algorithms to facilitate meaningful data reduction.

**Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)**

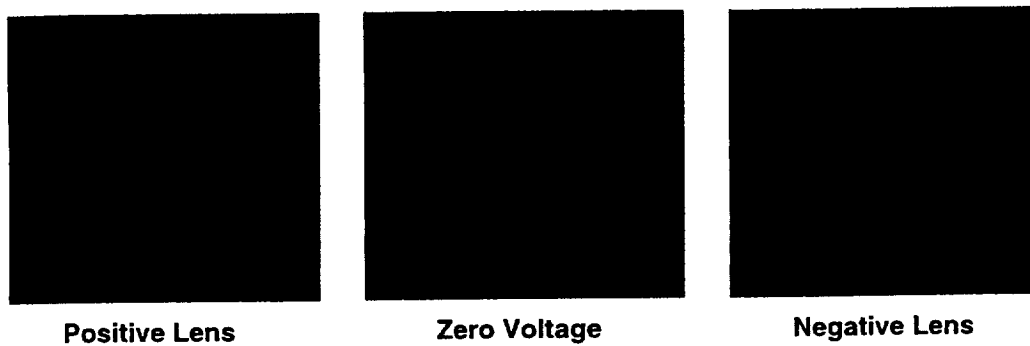


Figure 13. Typical Interferometric Raw Data.

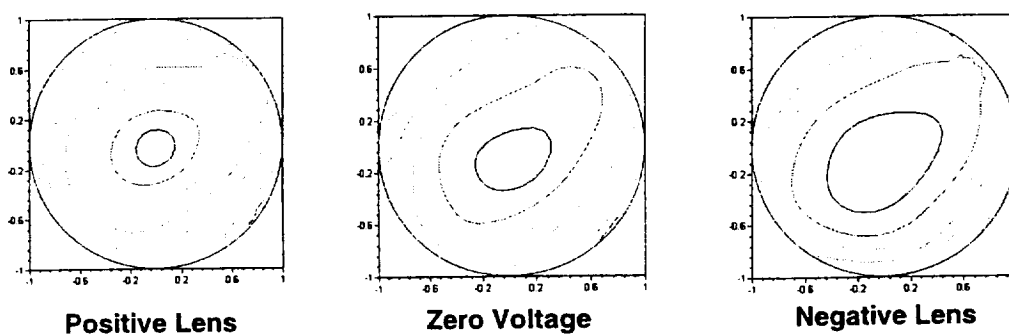


Figure 14. Typical Reduced Data Showing Fringe Contour Plots.

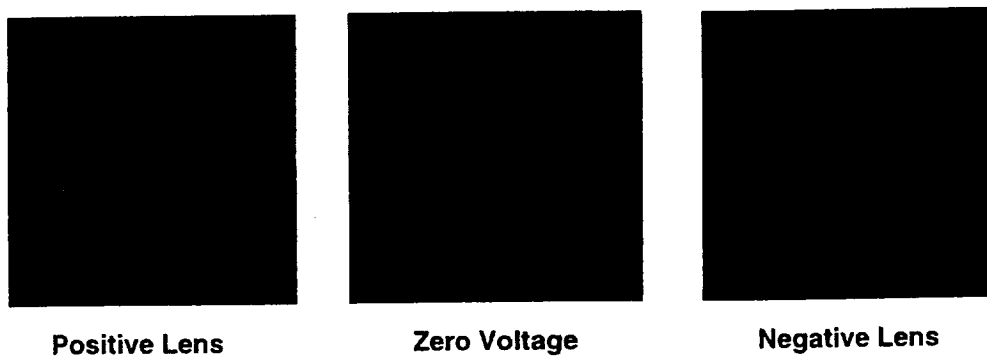


Figure 15. Averaged Data to Generate Synthetic Fringe Plots.

Final Report for NAS8-00118
Adjustable Focus Optical Correction Lens (AFOCL)

Conclusions:

The CAO has demonstrated that the PLZT based technology is capable of producing a variable or adjustable focus lens. A vendor was identified, a test device was designed and procured, and initial testing performed. As expected, the optical power is greater in the positive lens configuration than the negative lens configuration. However, there appears to be significant amounts of bias in the lens to begin with, even when no voltage is applied. This is consistent with the imaging data acquired and is likely attributable to the mounting procedure used by NIPT and UCSD. The substandard quality of the optical mounting and fabrication of the device places an overwhelming bias on the measurements making it difficult to separate performance from poor manufacturing. While issues of optical bonding and attachment of electrodes are all technologies readily available from the electronics industry, NIPT has very limited access to equipment and processes to improve their processes. Given the current limited capabilities of UCSD/NIPT, it is doubtful that the quality of their production could be significantly increased without unreasonable increases in financial backing that is not evident at this time.

Proposed Plan of Action:

- Continue with the testing of the existing device, especially advanced interferometry to better characterize the performance of the device in spite of the strong bias from the poor production processes. This needs to include investigation of data reduction algorithms that can function over apertures containing severe phase changes due to the localized bad areas attributed to bonding quality.
- Expand the optical testing to investigate polarization effects and optical material effects and investigate whether using the Mueller Matrix Imaging Polarimeter will yield any meaningful results given the large biases and aberrations present in the current device.
- Investigate image quality measurements using the Nodal Slide experimental apparatus possessed by the CAO.
- Delay procurement of another device until either: (1) NIPT demonstrates greater capability in bonding processes; (2) an alternative vendor can be identified.

| REPORT DOCUMENTATION PAGE | | | | Form Approved OMB No. 0704-0188 | |
|--|-------------|----------------|----------------------------|--|---|
| <p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p> | | | | | |
| 1. REPORT DATE (DD-MM-YYYY) | | 2. REPORT TYPE | | 3. DATES COVERED (From - To) | |
| 7/24/01 | | FINAL | | 5/10/00--5/9/01 | |
| 4. TITLE AND SUBTITLE Adjustable Focus Optical Correction Lens (AFOCL) | | | | 5a. CONTRACT NUMBER | |
| | | | | NAS8-00118 | |
| | | | | 5b. GRANT NUMBER | |
| | | | | 5c. PROGRAM ELEMENT NUMBER | |
| 6. AUTHOR(S) Dr. Bruce Peters | | | | 5d. PROJECT NUMBER | |
| | | | | 5e. TASK NUMBER | |
| | | | | 5f. WORK UNIT NUMBER | |
| | | | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | | | | 8. PERFORMING ORGANIZATION REPORT NUMBER | |
| UAH Huntsville, AL 35899 | | | | 9 | |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | | | 10. SPONSOR/MONITOR'S ACRONYM(S) | |
| | | | | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) | |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT | | | | | |
| 13. SUPPLEMENTARY NOTES | | | | | |
| 14. ABSTRACT | | | | | |
| 15. SUBJECT TERMS | | | | | |
| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | 19b. TELEPHONE NUMBER (Include area code) |

